THE DIRECT INJECTION OF ELECTRON PULSES INTO AIR--AN SREMP SIMULATION TOOL*

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ABSTRACT

Proper simulation of a source-region EMP environment requires the presence of time-varying air conductivity and space current. In the experiments described here, these features are produced by the AURORA Flash X-Ray Machine operating in the electron mode, rather than the less efficient bremsstrahlung mode. The primary goal of this experiment was to achieve a high dose over a large volume with a fast rise time. A great concern to the experimenters was overcoming the hose instability with its problems of unpredictability and nonuniformity. This was done by passing the electron beam (8.5 MeV, 200 kA, 200 ns), produced from a 53 cm diameter toroidal cathode, through a 0.15 cm steel window into the exposure room. This procedure scattered the beam enough to inhibit beam instability.

Theoretical predictions were made by using a one-dimensional electron transport code. Experimental measurements made were voltage and current machine diagnostics, exposure room mapping with CaF_2:Mn thermoluminescent dosimeters, scintillator photodiode, open shutter photography, current density measurements, microwave transmission determination of ionization levels, and loop and monopole antenna coupling measurements.

INTRODUCTION

The AURORA electron beam has been used in various forms inside drift chambers since 1973.[1] Now for the first time the electron beam from one of the four arms of AURORA has been brought directly into the test cell at atmospheric pressure in order to provide fast-rising, high-dose, air ionization for source region electromagnetic pulse (SREMP) simulation.

The electromagnetic pulse accompanying a nuclear blast is caused by gamma radiation from the device and its surroundings.[2] The gammas, through Compton interactions with air molecules, release high-energy electrons which create many additional free electrons in the process of slowing down. The charge separation and current thus produced act as sources for local electric and magnetic fields--and also, if asymmetry introduces multipole moments, for radiated fields. The region around the bomb, characterized by gamma flux, ionization, and Compton current, is thus known as the source region, and the resulting fields represent the SREMP.

In view of the ban on atmospheric testing, experimenters are forced to rely on simulation methods as a source for useful data. A large facility using pulsed-power technology is required to produce an EMP throughout a relatively large volume. Such facilities have been constructed for simulation of the radiated region, but not for the source region. Such a simulator would produce high-level ionization and distributed current, as well as the appropriate fields. The DNA-HDL AURORA Flash X-Ray Facility, which produces all these features in a 20 x 12 x 5 m test cell, has proved useful for SREMP studies, but, in the most commonly used bremsstrahlung mode, suffered from several limitations.

One limitation was the inability to obtain a high dose (1000 rad) over a large volume (characterized by lengths of several meters). Another severe limitation, for simulation, was the AURORA pulse shape--a rather symmetrical waveform which rises slower and falls faster than desired. A faster rise time is required in order to simulate EMP coupling to relatively small objects, such as whip antennas, whereas a slower fall would be needed in order to deal properly with coupling to very large objects, such as long cables. Other limitations are consequences of the finite size and metal enclosure of the test volume.

The greatest advantage of simulating the source region EMP by direct electron injection[3] is that this method of simulation can produce driver currents and air conductivity that are over a hundred times greater than those produced by bremsstrahlung simulation. This has the disadvantage, however, of the absence of hard gamma rays.

The experiments described here represent an attempt to deal with the dose-level and rise time problems. (The metal-wall and volume problems can be dealt with only by enlarging the test cell.) The energy of the Marx storage banks can be more efficiently made available for air ionization and space current by (a) allowing the electrons to penetrate the test cell directly, without the intermediate bremsstrahlung conversion step, and (b) aiming the beam straight into the room, rather than angling it for focussing purposes. The tests reported here exhibit a sharpened rise time. The mechanism is not altogether understood, but appears to be primarily the absorption and scatter of low energy electrons from the beam.

EXPERIMENTAL ARRANGEMENT

The electron beam was transmitted through a thick window to introduce scattering and suppress the hose instability.[4,5] The betatron wavelength was made large by the use of the largest diameter cathode available. The effect of the window was calculated using the TIGER[6] Monte-Carlo type code.

The electron beam diode, mounted on the lower left coaxial line, is shown in figure 1. The beam window diameter is 90 cm. The center line is 119 cm above the floor. The test cell is a completely metal enclosed room (the metal floor is under 3 in. of concrete). The vacuum coax has been bent 45° in order to bring the beam in parallel to the floor.

The pulser diagnostics were tube voltage, coax voltage, and three return current monitors. The beam diagnostics were open shutter photography, thermoluminescent dosimeters (TLDs), photodiodes, current loops, microwave attenuation, and a variety of antennas.

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Proper simulation of a source-region EMP environment requires the presence of time-varying air conductivity and space current. In the experiments described here, these features are produced by the AURORA Flash X-Ray Machine operating in the electron mode, rather than the less efficient bremsstrahlung mode. The primary goal of this experiment was to achieve a high dose over a large volume with a fast rise time. A great concern to the experimenters was overcoming the hose instability with its problems of unpredictability and nonuniformity. This was done by passing the electron beam (8.5 MeV, 200 kA, 200 ns), produced from a 53 em diameter toroidal cathode, through a 0.15 em steel window into the exposure room. This procedure scattered the beam enough to inhibit beam instability.

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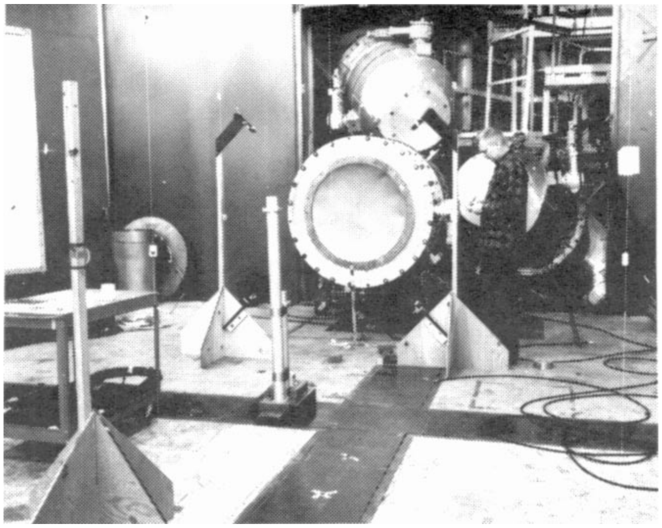

Figure 1. Electron Beam Diode Arrangement.

SUMMARY OF THE AURORA ELECTRON BEAM PARAMETERS

Diode voltage	8 MV
Diode current	200 kA
Pulse width	200 ns
Cathode type - annulus	26 cm Major Radius 2.5 cm Minor Radius
Anode - cathode gaps	56 cm, 28 cm, 18 cm
Beam window	0.15 cm thick steel ($1.2\ g/cm^2$)
Calculated:	
scatter angle	35° av
energy loss	2 MeV
transmitted charge	24 mC
Net current	apprx. 50 kA
Betatron wavelength	<2.3 m

ELECTRON BEAM MEASUREMENT

Open Shutter Photos - Figure 2 shows the electron beam emerging from the diode and traversing the test cell. One can see about 15 m of drift distance. The beam is rising, probably due to unbalanced return current forces caused by the beam's proximity to the floor upon injection. The beam appears to be free of the hose instability and appears to pinch somewhat just in front of the window. It apparently does not quite reach the end of the test chamber, which is near the end of the electron's range.

Thermoluminescent Dosimetry - In order to determine the extent of the ionization produced by the electron beam, a three-dimensional grid was established in the test cell. TLDs were typically deployed in vertical planes set at 1, 4, 7, 10, and 16 m from the beam window.

Each TLD measurement point was always occupied by two TLDs: one enclosed in an aluminum capsule of $1\ g/cm^2$ wall thickness, the other bare. Since the total stopping power of aluminum for 0.3 to 9.5 MeV electrons is 1.7 ± 0.2 MeV-cm^2/g, the energy loss in the 1 g/cm^2 capsules was $\simeq$ 1.7 MeV. At each measurement location we therefore had one TLD which could detect all electrons with energies greater than 25 to 30 keV and one which was sensitive only to electrons above $\simeq$ 1.7 MeV.

The TLDs which were used for this experiment were Teledyne-Isotopes type SD-CaF_2:Mn-0.4L. These TLDs are discs of Teflon, 6 mm in diameter by 0.4 mm thick, containing 5% by weight of manganese doped calcium fluoride. Calcium fluoride has a collision stopping power of 1.55 ± 0.1 MeV-cm^2/g for electrons between 0.5 and 9.5 MeV. The dose deposited in such a TLD by electrons can be shown to be given by

$$D_{TLD} = 1.55 \times 10^{11}\ \text{rad/C-cm}^2.$$

Thus, the TLDs give us not only a measure of the ionization produced by the electron beam, but also the charge density in the beam.

Figures 3 and 4 show the isodose contours of the electron beam at 1, 4, 7, 10, and 16 m from the beam window for the 28 cm and 56 cm A-K gaps. We see that the beam intensity is falling off sharply between 10 and 16 m but is holding its shape. The beam rises from the test cell floor until about 10 m where it levels off at the room center. The center of the injected beam is shown and is 119 cm above the floor. If one integrates the charge density over the beam area it is seen that the total charge is constant to 4 m and is about the 20 mC predicted by the TIGER code and pulser diagnostics. The ratio between the 1 g/cm^2 shielded TLDs and bare ones is also in agreement with that predicted by the TIGER code.

Figure 2. Electron Beam Traversing AURORA Test Cell.

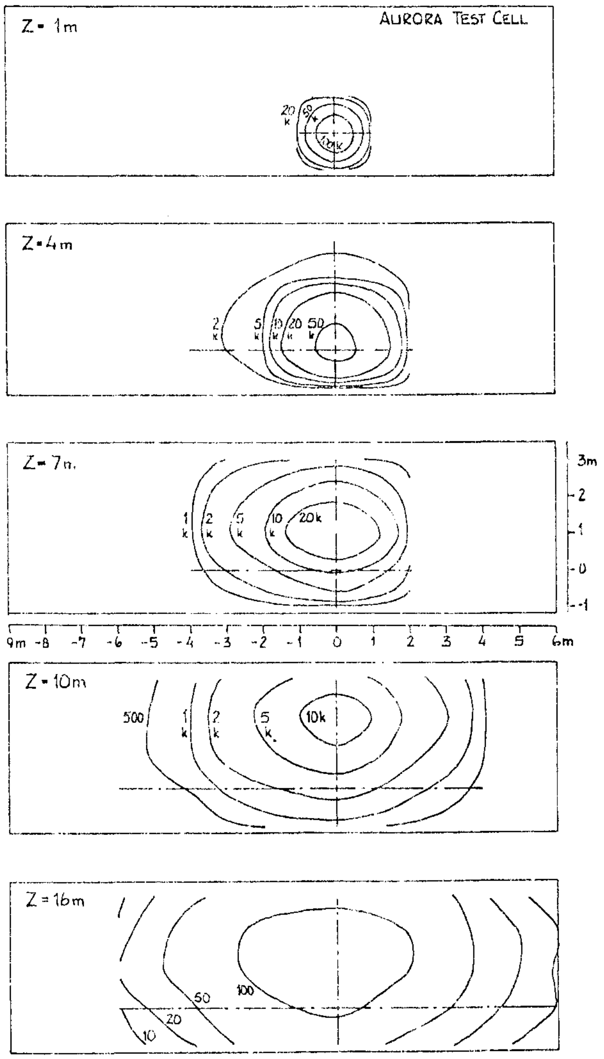

Figure 3. Isodose contours, rad(Si), bare TLDs; A-K gap = 28 cm.

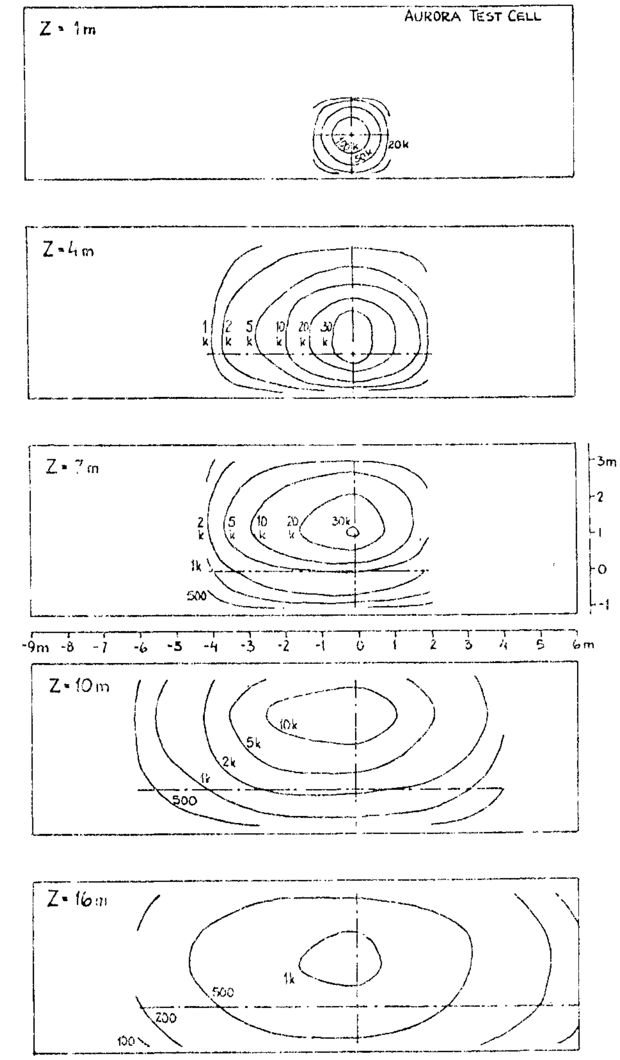

Figure 4. Isodose contours, rad(Si), bare TLDs; A-K gap = 56 cm.

Scintillator-Photodiode Measurements - Time resolved measurements of the electron beam were made at a distance of 2.4 m at heights of (PD 4) 14, (PD 3) 75, and (PD 2) 136 cm above the floor. These detectors consisted of a Cerenkov radiator coupled to a fast vacuum photodiode. The results are shown in figure 5 where the three pulses for each of the gaps and for the bremsstrahlung case are shown. It is clear that the leading edge of each pulse is nearly identical but that the detectors nearer the floor have less late time pulse. The beam is either moving up or decreasing in diameter with time. The open shutter photographs show that the top detector is about in the center of the beam.

Current Density Measurements - Figure 6 shows the pulse from a current loop that is in a shielded cage (J-dot sensor) and responds only to the net current passing through the cage. It is therefore a current density measurement. The peak current density shown of 1400 A/m^2 corresponds to 2 to 4 krad depending on the amount of current neutralization occurring. This is in good agreement with the TLD data.

Air Conductivity - Experiments using a 450 MHz microwave signal in a large (type 2300) waveguide showed (Figure 7) the envelope of the signal decreasing with the pulse shape, as the air conductivity increased.

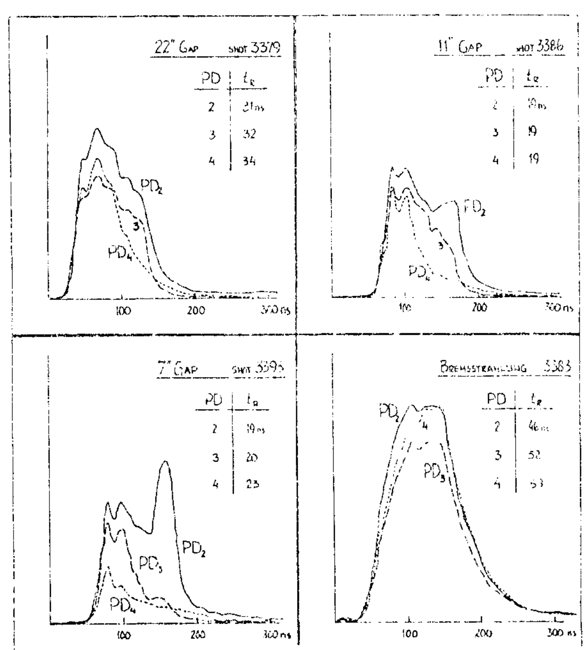

Figure 5. Summary and Comparison of Pulse Shapes.

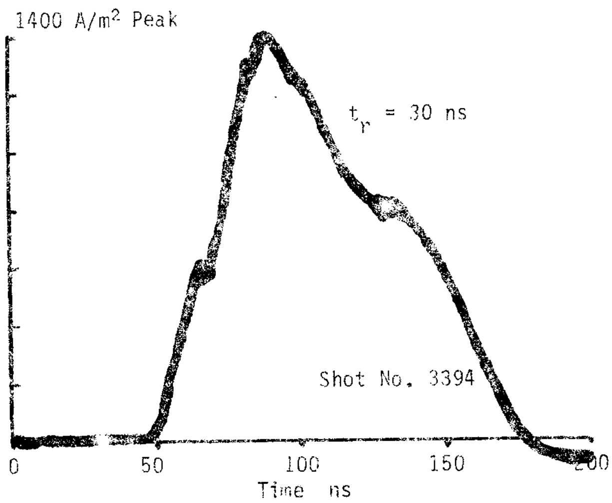

Figure 6. Current Density (J-Dot Sensor) Pulse.

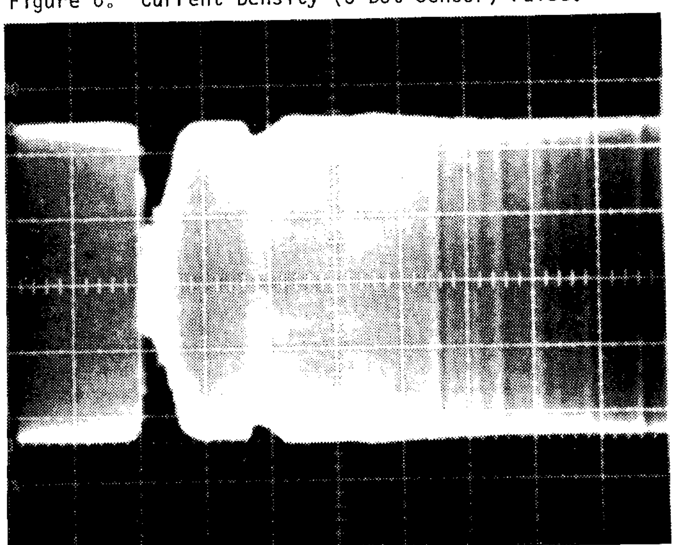

Figure 7. Waveguide Absorption Measurement (1V/DIV, 200 ns/DIV).

CONCLUSIONS AND RECOMMENDATIONS

It has been shown that a reasonably uniform and reproducible electron beam can be launched into the AURORA test cell. The beam can be diagnosed and is suitable for SREMP experiments and other applications. There is no evidence of the hose instability, and the window survived the thirty shots taken to date.

The results reported here clearly point the way to a very cost-effective enhancement of the ability of the AURORA facility to provide useful SREMP coupling data. Work should continue on optimizing the vacuum coax and diode geometry in order to produce efficient dosing of the test cell and obtain a sharply rising waveform. The experiments must be extended into multiple beams using the remaining AURORA lines. This work carries great implications for future experimental work in EMP environment studies, coupling studies, and subsystem testing, as well as for the development of future SREMP simulation schemes.

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